Directional Imaging Stack (DIS) for Shot Based Pre-stack Depth Migrations

Wilfred Whiteside, Alex Yeh and Bin Wang*

Summary

Shot based pre-stack depth migrations such as RTM are used to generate a partial image volume for each input shot gather. The conventional migrated image formed by summing together these partial images is often less than optimal in terms of signal to noise, and generally contains unwanted migration artifacts. Recently, the industry has found that non-equal weighting can be used to enhance the image quality. In this paper, we present our weighted stacking methodology called Directional Imaging Stack (DIS), taking into account source direction as is the industry standard, but further taking into account survey geometry, and various selective stack criteria which bring significant additional uplift.

Introduction

For Common-offset based Kirchhoff migration, proper muting before stacking is a key to improve the image quality. However, shot based pre-stack depth migrations such as RTM involve the formation of a partial image volume for each input shot. These partial images are completely summed together to form the final image, conventionally using equal weights. Each partial image contains primary reflection energy from the geologic structures we desire to image. It also may contain artifacts we call noise such as multiples and converted waves; and migration artifacts such as swings arising from non-uniform illumination either due to non-uniform acquisition sampling or focusing and defocusing effects of wave-propagation. Much of the noise, particularly migration swings, can be distinguished from structural energy based on dip, utilizing dip illumination methodologies as described in Qin et al. (2005) and Wang et al. (2010). Additionally, energy from a given region of a reflection event appears in multiple partial images from different reflection angles with a variable amount of signal to noise present in the vicinity. The signal to noise ratio in a given region is thus highly dependent upon the local structural dip, the source to image point offset, and the shooting direction. The industry has recently begun to incorporate unequal weighting into the final image formation process to optimize structure by taking into account the source direction with respect to image location (Xu et al., 2011). Similar to Kirchhoff muting before stack, the weighted sum scheme enables selective stacking to avoid adding into the final image unwanted noise and artifacts, to therefore improve the final image quality.

In this paper, we present our methodology of weighted stacking called Directional Imaging Stack (DIS). In our methodology, not only do we take into account the source directivity as is the industry standard, but the survey geometry is also taken into account. We have found significant uplift from incorporating shooting azimuth as an additional dimension for separating reflection energy into bins. Based on the imaging objective, different selective criteria for stacking can also be used. We discuss and show real data examples utilizing different weighting schemes. Additionally, we discuss practical aspects of each approach.

Method

Typically, after raw shot image volumes have been generated from a shot based pre-stack migration methodology such as RTM, the shot images are coarsely binned according to their shot to image point offset vector. The partial images in each bin are summed together with equal weights to form an array of directionally dependent images. By properly choosing unequal weights as a function of position, the directionally dependent partial images can be stacked to form a final image often with significant improvement of signal to noise around structures.

Figure 1 shows the typical industry standard 3x3 configuration, though arbitrary grids such as 4x5 have been used, and we have seen resulting uplift from better separation of structure and noise energies. The typical 3x3 grid dimensions are 2 to 3 km on a side. Outside bins extend outward without limits. The partial images within each bin are summed together using equal weights to form DIS partial images, nine in the case of 3x3. The process can also be expanded to include an additional dimension for DIS image formation, incorporating shooting direction (nominal source/receiver azimuth).

The next step is the calculation of spatially dependent weights for stacking the DIS partial images into a final image. There are several approaches that can be used for minimizing signal to noise relative to the structural dips we wish to optimize, two of which are discussed below.

One approach is to form a pilot or target image by equal weight stacking and to apply structural smoothing and filtering to enhance the structural clarity and remove noise. The target image is assumed to represent the signal and the stacking weights are then determined by least squares to maximize the signal to noise ratio, where signal is defined

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as the stacking component matching the target image which minimizes the remaining residual component of the image which is treated as noise. This approach works well in areas where there is no conflicting dip. In areas with conflicting dip such as around edges of salt and fault zones, this simple approach tends to enhance the dominant dips relative to the weaker events. In the case of faulting, it is typically the faults themselves that are damaged, and around edges of salt it is typically the sediment truncation that suffers. The salt sediment truncation is easily remedied using masking to treat the sediment portion separately from the salt portion. For faulting, the problem becomes more difficult as the conflicting dips are completely intermingled.

A second approach involves treating each DIS partial image independently. Each partial image is scanned to compute the dip field which maximizes windowed semblance. A function of the semblance fields is used to determine the stacking weight fields. This approach can handle conflicting dip provided that the conflicting energy is split between different DIS partial images. This is often the case for faulted events due to the greater aperture needed to image them relative to the aperture required to image the sediment layers. However, in some places this approach is more prone to enhancing swing noise or other energy that is coherent within a DIS partial image at the expense of underlying structure. Overall, this second approach is generally more robust. This approach can be modified to be more targeted by measuring the windowed dip semblance within each DIS partial image based on a common target dip field generated from a conventional equal weight stack suitably enhanced.

Examples

In our first example, we study the effect of utilizing more generalized grids than the standard 3x3 case. Figure 2 displays three RTM images from a Gulf of Mexico (GOM) survey, comparing the conventional equal weight stack (Figure 2a) against our 3x3 (Figure 2b) and 4x5 (Figure 2c) DIS results. In this case, the dip semblance approach was used, where each image is dip scanned independently and the weights are determined as a function of the semblances. The 3x3 image shows significant reduction in noise and increased structural clarity. It is interesting that further uplift is obtained using a 4x5 DIS approach. Separating into 20 partial images rather than nine improved the separation of structural events and noise, allowing the approach to effectively mask out more noise with less damage to the signal. This shows the importance of flexible and more generalized binning in optimizing the final image quality. Similar uplift has been observed in the target image based DIS approach as well as in the semblance based target dip field approach.

The first example isolated the effect of partial image separation based solely on source to image point vector offset. Shooting direction was not taken into account. In this second example we isolate the effect of shooting azimuth by splitting the data according to shooting direction but without considering the source to image offset vector. Here we migrate multi-azimuth input data from a GOM survey set that was acquired in both east-west and north-south shooting directions. Only two partial images are formed, one from conventional stacking of shot images from east-west shooting and the other from similarly stacking the acquired north-south shots. The conventional stacking results and the DIS weighted stacking approach are shown in Figures 3a and 3b, respectively. Beneath and around the overturned salt body, the sediment shows improvement in structural continuity with a significant reduction of migration artifacts. This example highlights the importance of going beyond the conventional source to image point binning approach and incorporating the extra binning dimension of shooting azimuth.

The DIS approach, as mentioned earlier, applies to any shot based migration. The prior examples have shown its use in enhancing RTM based final images. In Figure 4, we show the DIS technique similarly applied to a shot based beam migration in a region of the GOM dominated by tabular salt bodies. Figures 4a and 4b show the conventional and DIS results, respectively. As we saw with RTM, structural clarity is enhanced.

In our final example (Figure 5), we compare subsalt RTM images in an area that is particularly difficult to image due to the complexity of the salt geometry, poor illumination and therefore low signal to noise ratio. In this case, there is perhaps even greater uplift to be obtained from the image separation afforded by generalized DIS. Comparing the conventional stack (Figure 5a) and the DIS result, we can see important structural improvement. The blue arrow highlights an area that is initially difficult to interpret due to the lack of continuity. The DIS result, however, brings enough clarity that the underlying structure can clearly be seen.

Conclusions

Currently, the industry is adopting the idea of separately weighting partial shot images based on their source to image point vector offset in order to target structure and enhance signal to noise in final images. A 3x3 gridding approach is becoming an industry standard. In this paper, we have demonstrated that utilizing a more flexible binning

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grid system can lead to enhanced imaging results. We have also illustrated the importance of including the additional binning dimension of shooting azimuth. By incorporating these features into the DIS methodology we see that better separation of structural signal from noise and artifacts is achievable. The approach is equally applicable to shot based migrations such as RTM, wave equation and beam methods.

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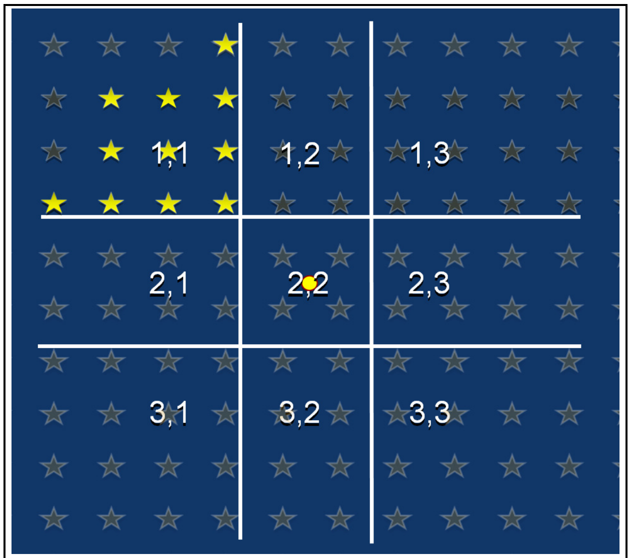

Figure 1: 3x3 source to image vector binning grid - yellow dot represents image point; yellow stars show sources within aperture contributing to partial image for quadrant (1,1)

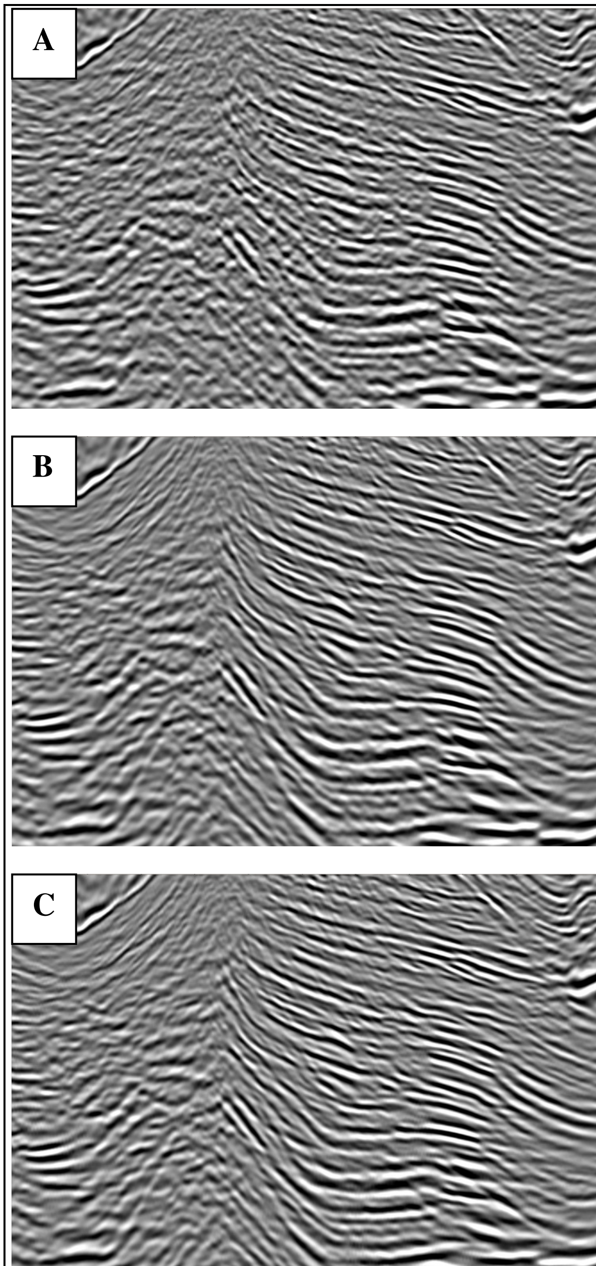

Figure 2: A) RTM image - equal weight stack. B) RTM image - DIS with 3x3 standard grid. C) RTM image – DIS 4x5 grid.

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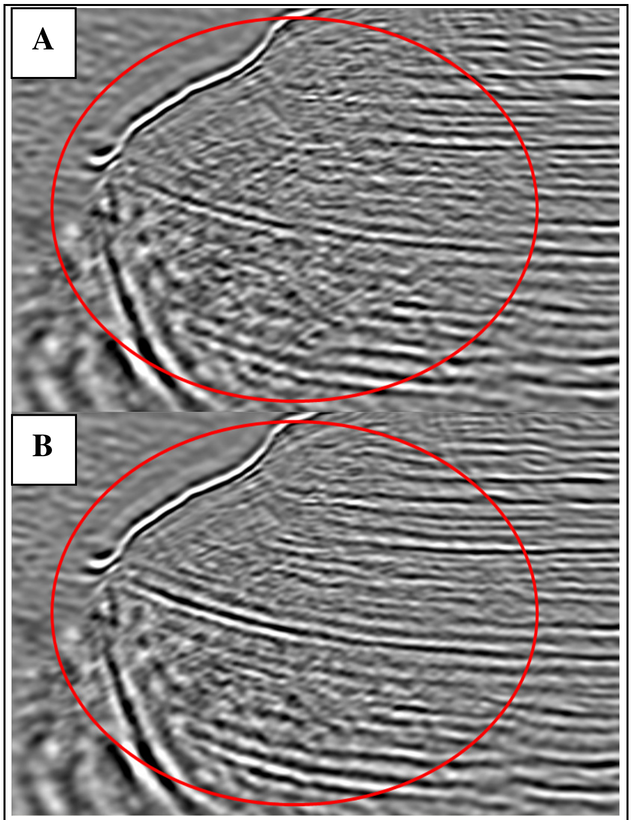

Figure 3: A) Conventional equal weight RTM image. B) Shooting azimuth only binning of RTM shot images using DIS with semblance based weighting approach.

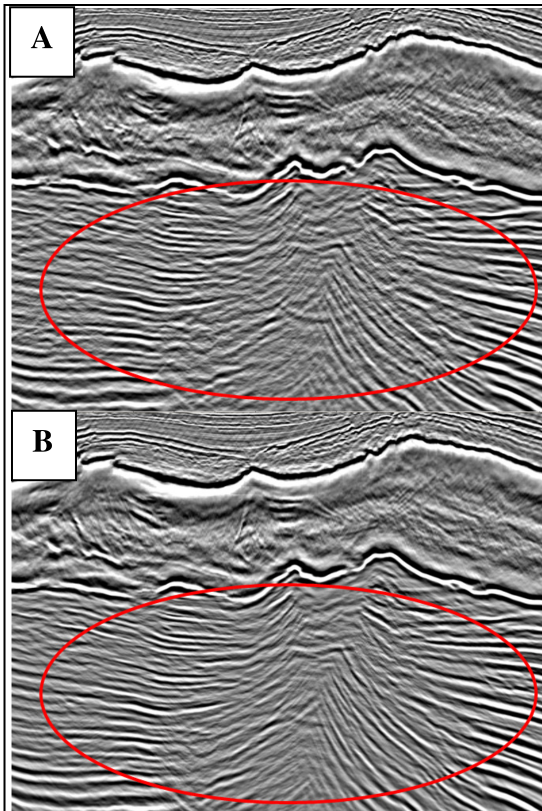

Figure 4: Shot based beam migration with A) equal weight stacking vs. B) stacking with target image based DIS.

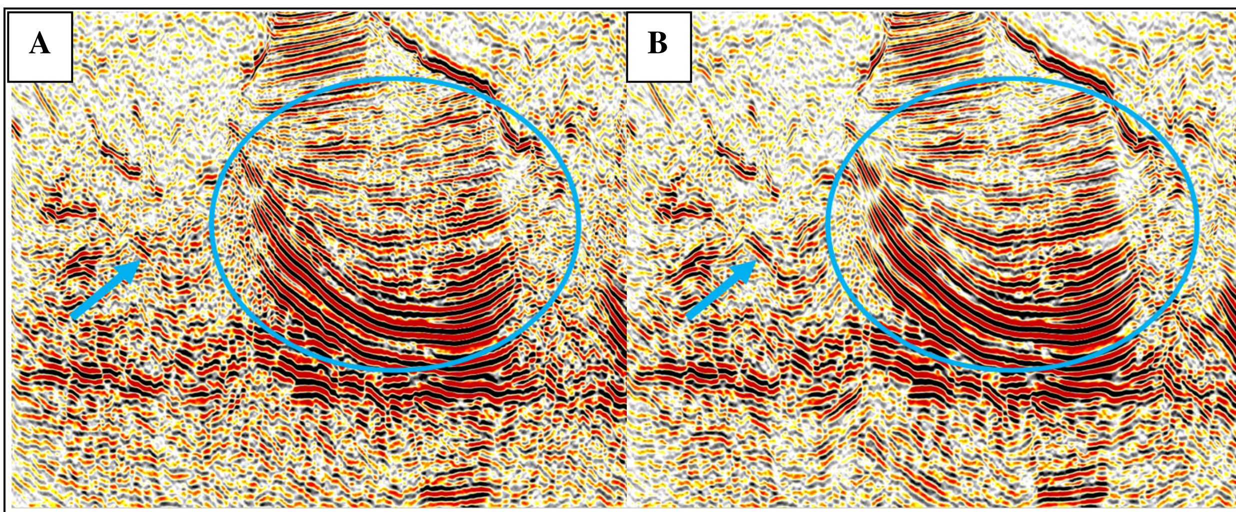

Figure 5: A) RTM with equal weight stack. B) RTM using DIS approach

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